Circuits and Signal Processing ET2405-d2

4e college

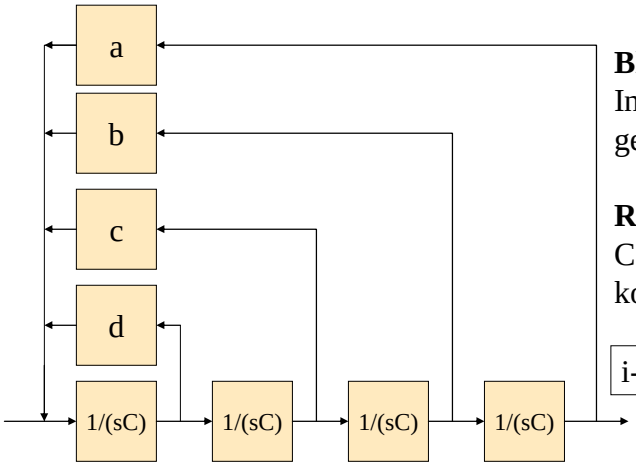
Arie van Staveren en Wouter A. Serdijn

Leerdoelen

Na afloop van dit college kan je:

- de vier basistypen integratoren beschrijven en hun voor- en nadelen aangeven;
- een instelschema afleiden bepalen;
- een kleinsignaalschema bepalen.

Integratoren

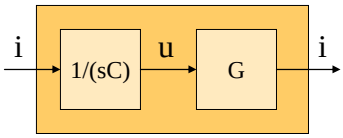


Blokschema:
Integratoren direct gekoppeld

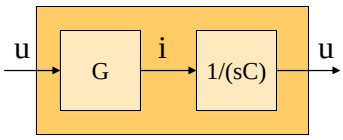
Realisatie:
C's niet direct te koppelen

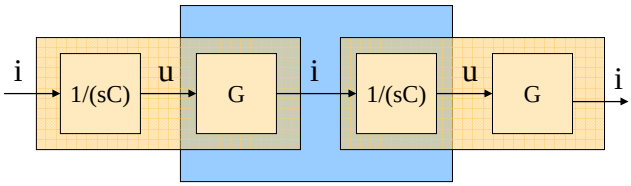
i-v of v-i converter

i-i integrator:

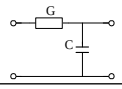
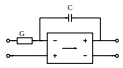
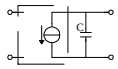
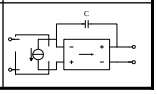


v-v integrator:

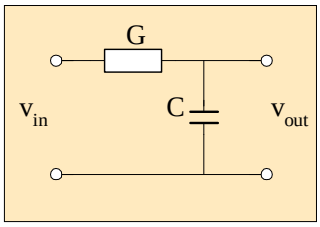




Classificatie integratoren

R \ C	Passief	Actief
Passief		
Actief		

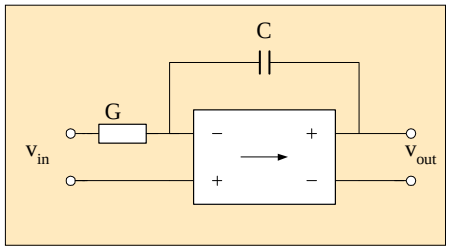
Conductantie - Impedantie



Geheel passief: geen complexe polen mogelijk!

Integrator is benaderd met: $H(s) = \dfrac{1}{1 + s\tau}$

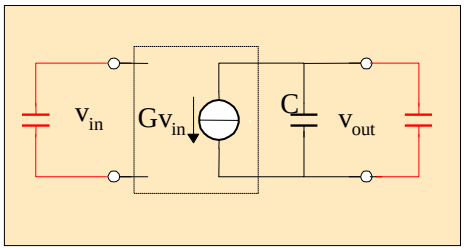
Conductantie - Transimpedantie



Uitsturing actieve deel kan rail-to-rail zijn ($-V_{CC}$ tot V_{CC})

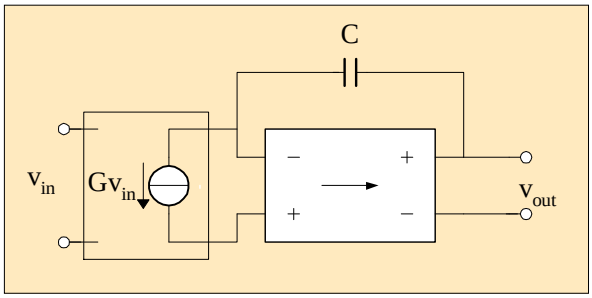
⇨ Goed voor DR!

Transconductantie - impedantie



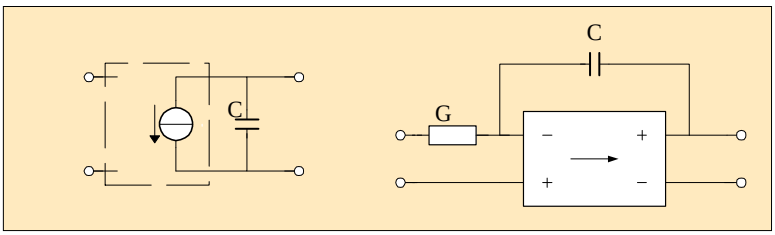
Parasitaire C's parallel aan gewenste C: HF mogelijkheid

Transconductantie - Transimpedantie



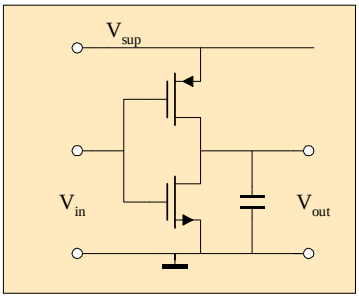
Nadeel: twee actieve delen

Voorkeur



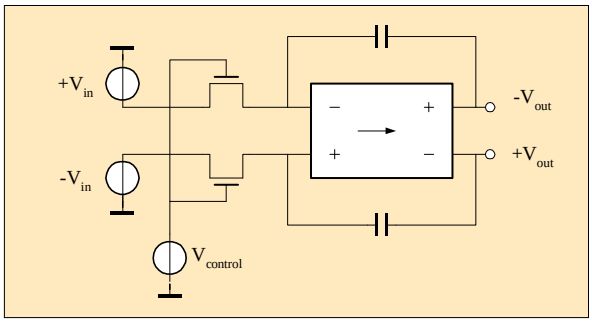
Vergt implementatie actief deel (nullor)
Dit doen we met opamps, FETs, BJTs, etc

Actieve saturatie integrator



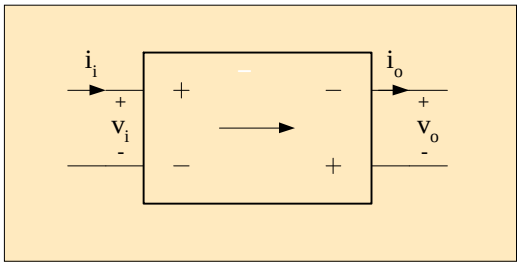
$$I_D = \frac{1}{2}\beta(V_{GS} - V_{th})^2$$

Passieve triode integrator



$$\frac{I_D}{V_{DS}} = \beta\left[(V_{GS} - V_{th}) - \frac{1}{2}V_{DS}\right] = \tilde{g}(V_{DS})$$

Uitgangspunt



Nullor : ideale versterker: $v_i = 0 \qquad -\infty < v_0 < \infty$

$i_i = 0 \qquad -\infty < i_o < \infty$

Benaderen met actieve componenten!

De kettingmatrix

$$\begin{pmatrix} v_i \\ i_i \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} v_o \\ i_o \end{pmatrix}$$

A,B,C,D : ketttingparameters

$$\boxed{\begin{aligned} v_i &= Av_o + Bi_o \\ i_i &= Cv_o + Di_o \end{aligned}} \Rightarrow A = \left.\frac{v_i}{v_o}\right|_{i_0=0}$$

Voor de nullor: $\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$

Eenvoudig in te zien?

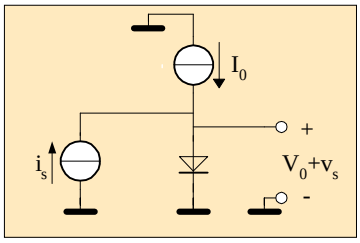
Kleinsignaalmodellen

Elektronische componenten hebben niet-lineair gedrag.

Bijvoorbeeld diode: $I_D = I_S\left[\exp\left(\frac{qV}{kT}\right)-1\right]$

Bekijk situatie:

I_0 : instelstroom
i_s : signaalstroom



$$\begin{cases} I_D = I_0 + i_s \\ V_D = V_0 + v_s \end{cases} \Rightarrow I_0 + i_s = I_S\left\{\exp\left[\frac{q(V_0+v_s)}{kT}\right] - \cancel{1}\right\} = \tilde{f}(V)$$

Taylorreeks rond V_0:

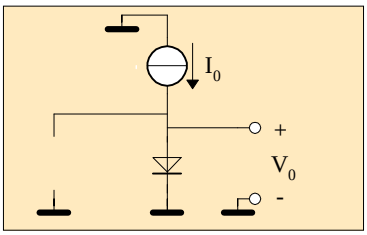
$$I_0 + i_s = \tilde{f}(V_o) + \left(\frac{d\tilde{f}(V)}{dV}\right)_{V=V_o} \cdot v_s + \underbrace{\left(\frac{d^2\tilde{f}(V)}{dV^2}\right)_{V=V_0} \cdot v_s^2 + \cdots}$$

$$I_0 + i_s = I_0 + g_m \cdot v_s + \text{distorsie}$$

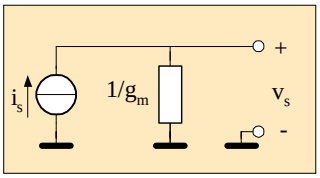
Als v_s relatief klein: $i_s = g_m \cdot v_s$

instelcircuit (signalen zijn nul):

$$I_0 \approx \tilde{f}(V_o)$$

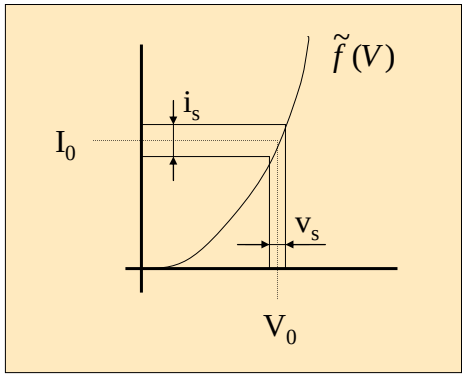


kleinsignaalcircuit (zonder instelgrootheden):



Vaak instelgrootheden gegeven; daaruit is kleinsignaalschema te bepalen

Grafische representatie

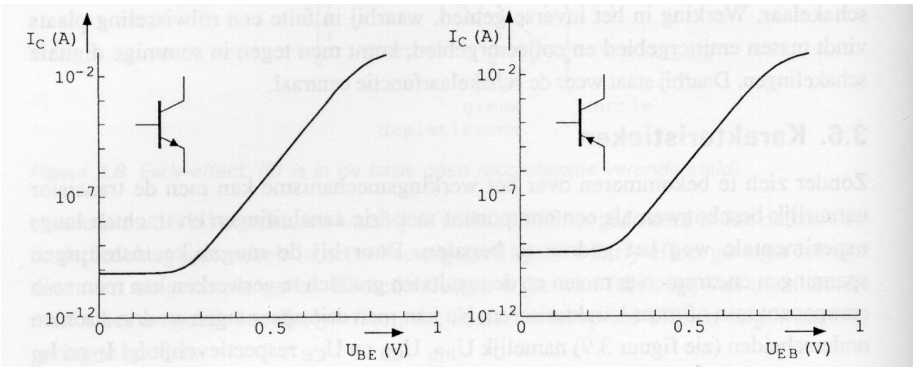


$$\left.\frac{d\tilde{f}(V)}{dV}\right|_{V_0} = \left.\frac{d\left[I_S \exp\left(\frac{qV}{kT}\right)\right]}{dV}\right|_{V_0}$$

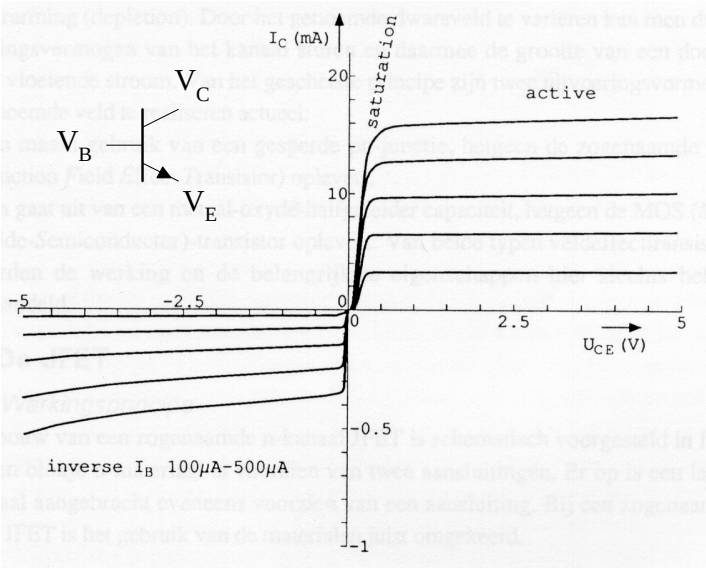
$$= \underbrace{I_s \exp\left(\frac{qV_0}{kT}\right)}_{I_0} \cdot \frac{q}{kT}$$

$$\boxed{g_m = \frac{qI_0}{kT}}$$

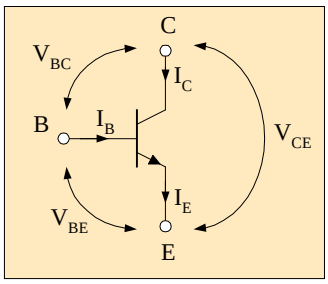
Bipolaire transistor



Relatie $V_{BE} - I_C$ exponentieel



Transportmodel



Transportmodel: beschrijft terminal stromen in de 4 werkgebieden van de transistor

Actieve gebied (NPN): $V_{BE} > 0$, $V_{BC} < 0$

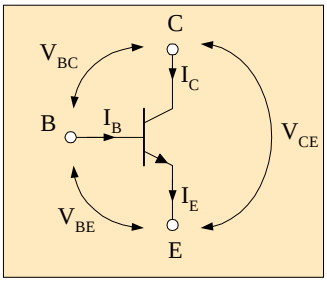
Actieve gebied

Transport model geeft in actieve gebied:

$$I_C = I_S \exp\left(\frac{qV_{BE}}{kT}\right)$$

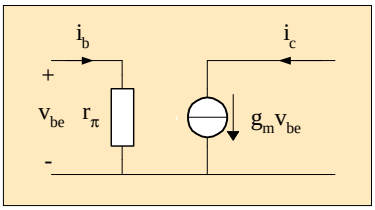
$$I_B = I_C / B_F$$

$$I_E = I_C + I_B$$



Kleinsignaalmodel:

$$I_C = I_S \exp\left(\frac{qV_{BE}}{kT}\right) \Rightarrow \left.\frac{dI_C}{dV_{BE}}\right|_{I_{C0}} \Rightarrow i_c = \boxed{g_m} v_{be} \qquad \left(g_m = \frac{qI_{C0}}{kT}\right)$$



$$I_B = I_C / B_F \Rightarrow \left.\frac{dI_C}{dI_B}\right|_{I_{C0}} \Rightarrow i_c = \boxed{\beta} i_b \qquad (\beta = B_F)$$

(bij dit eenvoudige model)

$$\frac{v_{be}}{i_b} = \frac{i_c / g_m}{i_c / \beta} = \frac{\beta}{g_m} = \boxed{r_\pi}$$

Capaciteiten

Transistorstructuur:

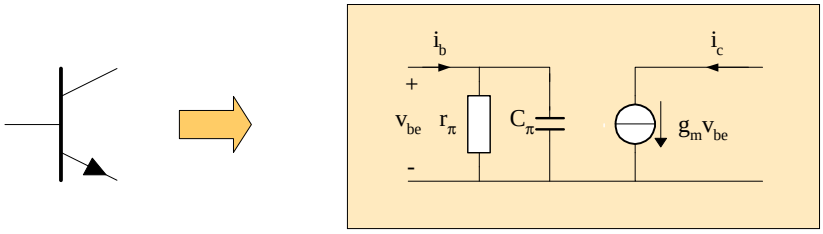
E	B	C
N	P	N
P	N	P

Tussen elke PN overgang een depletielaag ⇨ capaciteit

Dominant : capaciteit tussen B en E ⇨ C_π

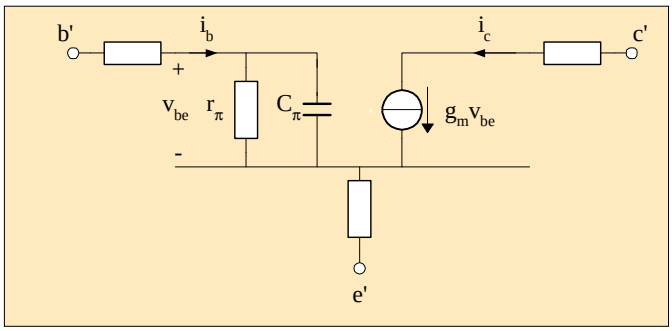
Op chip ook een capaciteit naar substraat!

kleinsignaalmodel



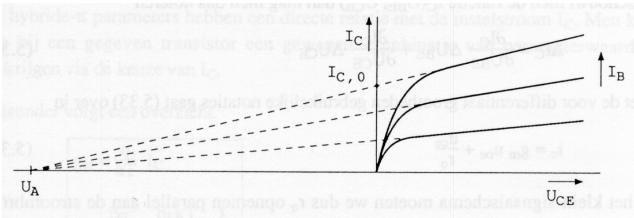
Bulkweerstanden

aansluitingweerstanden (in silicium):



Worden vaak in eerste instantie verwaarloosd!

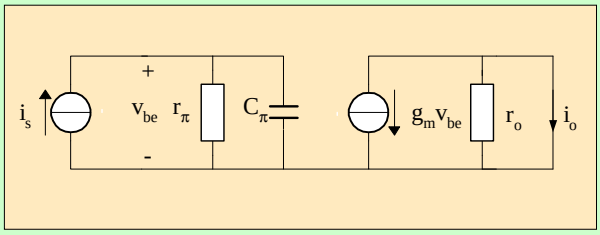
Uitgangsweerstand



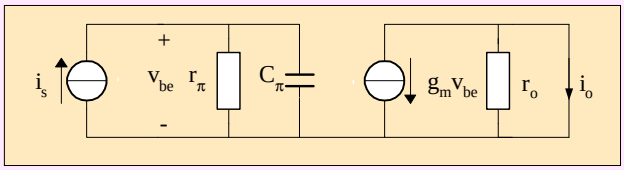
$$I_C = \underbrace{\left(1+\frac{V_{CE}}{V_A}\right)}_{\text{“Early effect”}} I_S \exp\left(\frac{qV_{BE}}{kT}\right) \Rightarrow \left.\frac{dI_C}{dV_{CE}}\right|_{I_{C0}} \Rightarrow i_c = \frac{1}{\boxed{r_o}} v_{be} \qquad \left(r_o = \frac{V_A}{I_{C0}}\right)$$

(wordt vaak in 1e instantie verwaarloosd)

Oefening



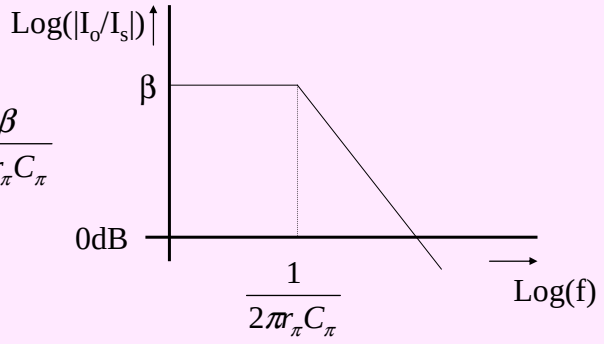
1. Bepaal $H(s) = i_o(s)/i_s(s)$ van deze CE trap als functie van g_m, β en C_π
2. Teken de bode plot (amplitude)
3. Bepaal de freq. waar $|i_o/i_s| = 1$



$$\left.\begin{aligned} V_{be} &= I_s \cdot \frac{r_\pi}{1+sr_\pi C_\pi} \\ I_c &= g_m V_{be} \end{aligned}\right\} \quad I_o = -g_m I_s \cdot \frac{r_\pi}{1+sr_\pi C_\pi}$$

$$\Rightarrow \quad I_o = -I_s \cdot \frac{\beta}{1+sr_\pi C_\pi}$$

$$\frac{I_o}{I_s} = \frac{-\beta}{1 + s r_\pi C_\pi}$$

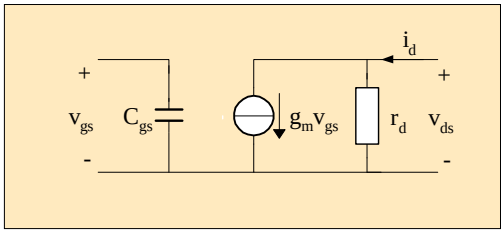


Voor $f >> \frac{1}{2\pi r_\pi C_\pi}$ imaginaire deel dominant:

$$\left|\frac{i_o}{i_s}\right| = \frac{\beta}{2\pi f r_\pi C_\pi} = 1 \quad \rightarrow \quad f = \frac{g_m}{2\pi C_\pi} = f_T$$

Transit frequency (figure of merit)

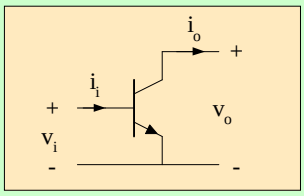
Veldeffecttransistoren



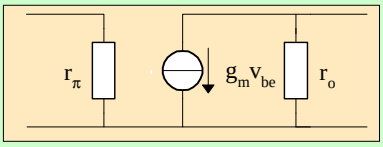
Voor JFET en MOSFET

Kettingmatrix CE trap

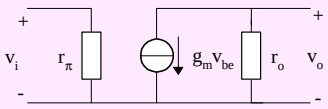
CE trap : common-emitter (in- en uitgang hebben emitter gemeen)



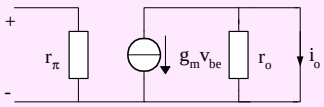
Bepaal kettingmatrix uitgaande van DC kleinsignaalmodel:



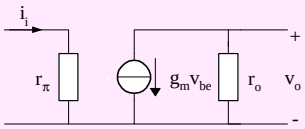
$$A = \left.\frac{v_i}{v_o}\right|_{i_o=0} = \frac{v_i}{-g_m v_i r_o} = \frac{-1}{\frac{qI_C}{kT}\frac{V_A}{I_C}} = \frac{-V_T}{V_A}$$



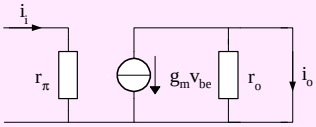
$$B = \left.\frac{v_i}{i_o}\right|_{v_o=0} = \frac{v_i}{-g_m v_i} = \frac{-1}{g_m} = \frac{-V_T}{I_{C0}}$$

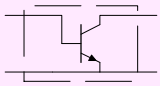


$$C = \left.\frac{i_i}{v_o}\right|_{i_o=0} = \frac{i_i}{-r_\pi g_m r_o i_i} = \frac{-1}{\beta r_o} = \frac{-I_{C0}}{\beta V_A}$$



$$D = \left.\frac{i_i}{i_o}\right|_{v_o=0} = \frac{i_i}{-r_\pi g_m i_i} = \frac{-1}{\beta}$$





Kettingmatrix bipolaire transistor:

$$\begin{pmatrix} -\dfrac{V_T}{V_A} & -\dfrac{V_T}{I_C} \\ \dfrac{-I_C}{\beta_F V_A} & \dfrac{-1}{\beta_F} \end{pmatrix}$$

V_T = 0.025 V
V_A = 100 V
I_C = 10 µA
β_F = 100

$$\begin{pmatrix} -2.5e-4 & -2.5e+3 \\ -1e-9 & -1e-2 \end{pmatrix}$$